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EP 0 244 924 B1

SCIENCE, vol. 213,no. 4506,July,24,1981,
Washington D.C. P. TIOLLAIS et al. "Biology
of Hepatitis B Virus" pp. 406-411

Description

BACKGROUND OF THE INVENTION

5 Hepatitis B virus (HBV) is the infectious agent responsible for several varieties of human liver disease. Many individuals who are infected by HBV suffer through an acute phase of disease, which is followed by recovery. However, a large number of individuals fail to clear their infection, thereby becoming chronic carriers of the infection. HBV infection is endemic to many parts of the world, with a high incidence of infection occurring perinatally from chronically infected mothers to their newborns. The number of chronic
 10 carriers worldwide has been estimated at over three hundred million. From this pool of carriers, hundreds of thousands die annually from the long-term consequences of chronic hepatitis B (cirrhosis or hepatocellular carcinoma).

The HB virion is composed of two groups of structural proteins, the core proteins and the envelope or surface ("S") proteins. In addition to being the major surface proteins of the virion, i.e., Dane particle, the
 15 "S" proteins are the sole constituents of Australia antigen, or 22 nm particles. The "S" proteins are the translational products of a large open reading frame (ORF) encoding 389-400 amino acids, depending upon serotype [Lo, S.J. et al., 1986, Biochem. Biophys. Res. Comm., 135, pp 382]. This ORF is demarcated into three domains, each of which begins with an ATG codon that is capable of functioning as a translational initiation site *in vivo*. These domains are referred to as preS-1 (108-119 amino acids), preS-2 (55 amino
 20 acids), and S (226 amino acids) in their respective 5'-3' order in the gene [Heerman, K.H. et al., 1984, J. Virol., 52, pp 396-402]. The six protein products derived from this ORF have the following compositions:

- 1) gp42 (42,000 dalton glycoprotein) = preS-1/preS-2/S (meaning preS-1, contiguous with preS-2, contiguous with S)
- 2) p39 (p = protein) = preS-1/preS-2/S
- 25 3) gp36 = preS-2/S (two glycosylation sites)
- 4) gp33 = preS-2/S (one glycosylation site)
- 5) gp27 = S (one glycosylation site)
- 6) p24 = S

All six proteins are present to an approximately equimolar extent in the HBV Dane particle. In the 22 nm
 30 particle, the 4 smaller proteins are present to an approximately equimolar extent, while gp42 and p39 are present in at most one or a few molecules per particle.

The 22 nm particles, or HB surface antigen (HBsAg) particles, have been purified from the plasma of chronic carriers. In terms of their plasma being particle-positive, these chronic carriers are referred to as HBs⁺. When these carriers have mounted a sufficient immune response, they can clear the infection and
 35 become HBs⁻. In terms of their formation of antibodies to HBs, these individuals are denoted anti-HBs⁺. In this way, anti-HBs⁺ is correlated with recovery from disease. Therefore, the stimulation or formation of anti-HBs⁺ by HB vaccine has been expected to confer protection against HBV infection.

This hypothesis has been testable experimentally. Outside of man, chimpanzees are the only species which is fully susceptible to HBV infection, as reflected in quantifiable markers such as HBs⁺, elevated
 40 serum levels of liver enzymes, etc. Chimpanzees have been vaccinated with three doses of purified HBsAg particles and then challenged with a large dose of infectious HBV. While mock-vaccinated animals have suffered the signs of acute HBV infection, the HBsAg-vaccinated animals have been protected completely from any signs of infection. Therefore, in this experimental system, HBsAg particles, composed of gp27 and p24 (S domain only), have been sufficient to induce protective immunity. Spurred by these observations,
 45 several manufacturers have produced HB vaccines composed of HBsAg particles.

Recent data have suggested that the preS-1 and preS-2 domains may play an important role in immunity to HBV infections [Neurath et al., Nature, 315, pp 154-6 (1985)]. Both antibodies to preS-1 (elicited by immunization with a peptide consisting of amino acid residues 10-32 of preS-1) as well as
 50 antibodies to preS-2 (elicited by immunization with a peptide consisting of amino acid residues 1-26 of preS-2) are capable of blocking the binding of HBV to human hepatoma cells *in vitro*; anti-HBs (sera from patients vaccinated with HBsAg lacking preS-1 or preS-2) is incapable of mediating this blocking event. If this *in vitro* event mimics *in vivo* infection, then pre-S (i.e., preS-1 and preS-2 *in toto* linked together) domains may represent the HBV binding site to its liver cell receptor, and anti-pre-S may block HBV attachment and initiation of infection. In addition, it has been found that anti-pre-S rises in titer during the
 55 recovery phase from acute HBV infection, indicating a role for these antibodies in recovery. Finally, it has been shown that vaccination of chimpanzees with a 108 amino acid pre-S polypeptide (residues 27-119 of preS-1 contiguous with 1-16 of preS-2) was capable of mediating some measure of protection against HBV challenge. In sum, these experimental observations have suggested that the pre-S domains are a useful

addition to present HB vaccines.

In order to expand the available supply of HB vaccines, manufacturers have turned to recombinant DNA technology to mediate the expression of "S" proteins. Among microbial systems, *Escherichia coli* and *Saccharomyces cerevisiae* have been used most commonly for the expression of many recombinant-derived proteins. Numerous attempts to express immunologically active HBsAg particles in *E. coli* have been unsuccessful [Fujisawa *et al.*, (1985) *Gene*, **40**, pp 23-29; Offensperger *et al.*, (1985) *P.N.A.S. USA*, **82** pp 7540-4]. However, *S. cerevisiae* has shown great versatility in its ability to express immunologically active HBsAg particles Valenzuela *et al.*, (1985), *Biotechnology*, **3**, pp. 17-20. These particles, when formulated into a vaccine, have proven capable of fully protecting chimpanzees against challenge with live HBV. Furthermore, yeast-derived HBsAg has been as effective immunologically in human clinical trials as plasma-derived HBsAg. Therefore, the utility of *S. cerevisiae* as a host species for directing synthesis of recombinant HBsAg is established firmly. In light of this, it would be desirable to express the entire pre-S domain linked to the S domain in an immunogenic particle.

In a variety of recombinant microbial expression systems, the synthesis of many different polypeptides has been shown to be deleterious to the host cell. As a consequence, there is selective pressure against the expression of such polypeptides, such that the only cells which accumulate in a scale-up of such a recombinant culture are those which have ceased to express the foreign polypeptide or express so little of the foreign polypeptide that the culture becomes an uneconomical source of that polypeptide. In some cases, the deleterious effect is so strong that when expression is driven by a strong constitutive promoter, newly transformed cells fail to propagate and form colonies on selective plates. These deleterious effects can be overcome by using an inducible promoter to direct the synthesis of such polypeptides. A number of inducible genes exist in *S. cerevisiae*. Three well-characterized inducible systems are the galactose (GAL) utilization genes, the alcohol dehydrogenase 2 (ADH2) gene, and the alpha mating factor gene.

S. cerevisiae has 3 genes which encode the enzymes responsible for the utilization of galactose as a carbon source for growth. The GAL1, GAL7 and GAL10 genes respectively encode galactokinase, α -D-galactose-1-phosphate uridylyltransferase and uridine diphosphogalactose-4-epimerase. In the absence of galactose, very little expression of these enzymes is detected. If cells are grown on glucose and then galactose is added to the culture, these three enzymes are induced coordinately, by at least 1,000-fold, at the level of RNA transcription. The GAL1 and GAL10 genes have been molecularly cloned and sequenced. The regulatory and promoter sequences to the 5' sides of the respective coding regions have been placed adjacent to the coding regions of the lacZ gene. These experiments have defined those promoter and regulatory sequences which are necessary and sufficient for galactose induction.

S. cerevisiae also has 3 genes, each of which encodes an isozyme of ADH. One of these enzymes, ADHIII, is responsible for the ability of *S. cerevisiae* to utilize ethanol as a carbon source during oxidative growth. Expression of the ADH2 gene, which encodes the ADHIII isozyme, is catabolite-repressed by glucose, such that there is virtually no transcription of the ADH2 gene during fermentative growth in the presence of glucose levels of 0.1% (w/v). Upon glucose depletion and in the presence of non-repressing carbon sources, transcription of the ADH2 gene is induced 100- to 1000-fold. This gene has been molecularly cloned and sequenced, and those regulatory and promoter sequences which are necessary and sufficient for derepression of transcription have been defined.

Alpha mating factor is a sex pheromone of *S. cerevisiae* which is required for mating between MAT α and MATa cells. This tridecapeptide is expressed as a prepropheromone which is directed into the rough endoplasmic reticulum, glycosylated and proteolytically processed to its final mature form which is secreted from cells. This biochemical pathway has been exploited as an expression strategy for foreign polypeptides. The alpha mating factor gene has been molecularly cloned and its promoter with pre-pro-leader sequence has been utilized to express and secrete a variety of polypeptides. As expected by their traversal of the rough endoplasmic reticulum and Golgi apparatus, foreign proteins can undergo both N- and O-linked glycosylation events. The alpha mating factor promoter is active only in cells which are phenotypically α . There are 4 genetic loci in *S. cerevisiae*, known as SIR, which synthesize proteins required for the repression of other normally silent copies of α and α information. Temperature-sensitive (ts) lesions which interfere with this repression event exist in the gene product of at least one of these loci. In this mutant, growth at 35°C abrogates repression, resulting in cells phenotypically α/α in which the alpha mating factor promoter is inactive. Upon temperature shift to 23°C, the cells phenotypically revert to α such that the promoter becomes active. The use of strains with a ts SIR lesion has been demonstrated for the controlled expression of several foreign polypeptides.

The entire hepatitis B virus pr -S antigen gene linked in one contiguous reading frame to the hepatitis B virus surface antigen gene has been expressed in *Saccharomyces cerevisiae*. The expressed protein aggregates into a particulate form which displays the major antigenic sites encoded by both domains,

thereby highlighting the utility of yeast as a host for the expression of the pre-S domain. This protein is useful in *in vitro* diagnostic systems and as a vaccine for the treatment and prevention of hepatitis B-virus-induced diseases and/or infections.

5 BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1A, 1B and 1C are schematic diagrams illustrating the construction of plasmids pYGAP/PSSΔ, pYGAP/PSSC, pYGAL/PSSΔ, pYGAL/PSSC, pYADH2/PSSΔ, pYADH2/PSSC, and pUC13/PSSC.

Figures 2 and 3 are schematic diagrams illustrating the construction of the alpha mating factor vector pJC197.

Figures 4A and 4B are schematic diagrams illustrating the construction of plasmid pYαMF/PSSΔS.

DETAILED DESCRIPTION OF THE INVENTION

15 The present invention is directed to a vaccine against hepatitis B disease comprising a polypeptide and a physiologically acceptable diluent, characterised in that said polypeptide has the pre-S1 domain lacking amino acids 2-15, the pre-S2 domain and the S domain.

Dane particles are utilized as the source of HBV nucleic acid for the isolation of the preS-1/preS-2/S ORF. The endogenous polymerase reaction is employed in order to produce covalently closed circular
20 double-stranded DNA of the HBV genome from the nicked and gapped form that resides natively in the HB virion. The repaired DNA is isolated and digested to completion with *EcoRI*. The *E. coli* cloning vector pBR322 also is digested with *EcoRI*, ligated to the HBV DNA and used to transform *E. coli*. Recombinant plasmids are selected, these containing the HBV genome in a circularly permuted form in which the *EcoRI* site divides the complete preS-1/preS-2/S coding region into a 5' domain of 0.4 kilobase pairs (kbp) and a
25 3' domain of 0.8 kbp. These two domains are subcloned for the eventual reassembly of the entire gene. For the 3' domain, pUC19 is digested with *EcoRI* and *BamHI*, then ligated to a synthetic oligonucleotide which consists of the final 5 nucleotides of the coding region, the stop codon, a *HindIII* site, and a *BamHI* end. The 3' portion of the preS-1/preS-2/S gene, consisting of a 0.8 kbp *EcoRI*-*AccI* fragment, is cloned into this vector. The 5' portion, consisting of a 0.3 kbp *BamHI*-*EcoRI* fragment, is subcloned into pUC18 in either of
30 two ways, depending upon whether (1) the complete ORF is to be expressed or (2) the putative hydrophobic signal sequence (amino acids 2-15) is to be eliminated. For the first strategy, pUC18 is digested with *HindIII* and *EcoRI* and ligated to a 72 bp synthetic oligonucleotide which reconstitutes the complete ORF from the *BamHI* site upstream, through the distal ATG and a 10 bp nontranslated leader sequence, to a *HindIII* compatible terminus. For the second strategy, there is ligated a 30 bp oligonucleotide
35 which performs an identical function but which eliminates the coding region for amino acids 2-15. The 0.3 kbp *BamHI*-*EcoRI* fragment of the 5' domain then is ligated into either of these oligonucleotide-linked cloning vectors. The 5' pUC18 and 3' pUC19 clones are amplified by growth in *E. coli*, and the coding regions are digested from the isolated plasmids as *HindIII*-*EcoRI* fragments. The 5' and 3' fragments are ligated, digested with *HindIII*, and the complete ORF with *HindIII* termini is cloned into pUC13 which had
40 been digested previously with *HindIII*. The complete ORF as a *HindIII* fragment is purified by preparative agarose gel electrophoresis for cloning into the GAPDH, ADH2 or GAL10 promoter expression systems.

The pBR322 plasmid containing the GAPDH expression cassette possesses a unique *HindIII* site between the GAPDH promoter and the ADH1 transcriptional terminator into which the complete ORF from pUC13 described above is inserted in the appropriate orientation. This 3.0 kbp expression cassette then is
45 removed by *SphI* digestion and ligated into the shuttle vector pC1/1 to replace the small *SphI* fragment. Vectors constructed in this manner are used to transform *S. cerevisiae* strain 2150-2-3 (Valenzuela *et al.*, Biotechnology 3:317-320, April 1985); however, plating out the transformation mixture onto selective plates results in no stable colony formation. The suspected toxicity of the expressed product is confirmed by the removal of the majority of the PreS1-PreS-2/S coding region and creation of a frameshift mutation by
50 *BamHI* digestion and religation of the plasmid; DNA prepared in this way efficiently transforms yeast cells.

The YEp52 *E. coli*/*S. cerevisiae* shuttle vector drives expression of foreign genes inserted at a unique *HindIII* site from the galactose-inducible GAL10 promoter. The PreS-1/PreS-2/S ORF (with *HindIII* termini) described above is ligated into the *HindIII* site of the vector. This recombinant plasmid is introduced to *S. cerevisiae* strain BY-19 (also known as DC04, Broach *et al.*, Cell 21: 501-508, 1980) and transformed clones
55 are selected. Cells are grown in synthetic selective medium containing glycerol-lactic acid. Subsequently, galactose is added to the cultures to induce expression. Lysates are prepared, resolved by sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) and Western blotted to nitrocellulose. A p39 product is found to be specific to preS-1/preS-2/S by virtue of its presence only in induced transformants

and its reactivity with convalescent human HB sera. Furthermore, lysates of transformants, but not wild-type *S. cerevisiae*, are positive for HBsAg by radioimmunoassay and are positive for pre-S by virtue of binding to polymerized human albumin, a binding which has been shown to be specific to the pre-S region. An immune-affinity column, bound with goat antibodies which recognize the particulate form of HBsAg, has been utilized to purify preS-1/preS-2/S from transformed *S. cerevisiae*. The eluted product is positive for HBsAg by radioimmunoassay, is positive for pre-S by polymerized human albumin binding, and is of particulate form in electron microscopy. These data demonstrate that the entire preS-1/preS-2/S protein is expressed in *S. cerevisiae* as a p39 protein present in particulate form. Such a particulate form which contains both HBs and pre-S antigens is effective as a HB vaccine and diagnostic reagent.

The pADH2Δ67(-1) *E. coli* cloning vector contains sequences which are capable in *S. cerevisiae* of driving expression of foreign genes inserted at a unique *Hind*III site from the *ADH2* (glucose-repressible) promoter. pADH2Δ67(-1) is digested with *Bam*HI and *Eco*RI, made flush-ended with the Klenow fragment of DNA polymerase I, and the 4.9 kbp fragment containing the *ADH2* promoter and terminator purified by preparative agarose gel electrophoresis. pUC7 is digested with *Pst*I, made flush-ended with T4 DNA polymerase, and ligated to the 4.9 kbp fragment. The resulting plasmid is digested with *Sal*I, and the 4.9 kbp fragment is purified by preparative agarose gel electrophoresis. pUC18 is digested with *Hind*III, made flush-ended with the Klenow fragment of DNA polymerase I, and self-ligated. The resulting plasmid is digested with *Sal*I and ligated to the 4.9 kbp *Sal*I fragment. The 1.2 kbp PreS-1/PreS-2/S ORF (with *Hind*III termini) described above is ligated into the *Hind*III site of this vector. The resulting plasmid is digested with *Sal*I, and the 6.1 kbp fragment is ligated into the *Sal*I site of the shuttle vector pC1/1. Plasmid pC1/1 is a derivative of pJDB219 in which the region corresponding to bacterial plasmid pMB9 in pJDB219 was replaced by pBR322. This recombinant plasmid is introduced into *S. cerevisiae*, and transformed clones are selected. Cells are grown in synthetic selective medium containing 0.3% (w/v) glucose. Forty-eight hours later, following glucose depletion, lysates are prepared, resolved by SDS-PAGE and Western blotted to nitrocellulose. A p39 product is found to be specific to preS-1/preS-2/S by virtue of its presence only in transformants and its reactivity with convalescent human HB sera. Furthermore, lysates of transformants, but not wild-type *S. cerevisiae*, are positive for HBsAg by radioimmunoassay and are positive for pre-S by binding to polymerized human albumin. An immune-affinity column, bound with goat antibodies which recognize the particulate form of HBsAg, has been utilized to purify preS-1/preS-2/S from transformed *S. cerevisiae*. The eluted product is positive for HBsAg by radioimmunoassay, is positive for pre-S by polymerized human albumin binding, and is of particulate form in electron microscopy.

The alpha mating factor gene *MFα1* has been cloned onto a plasmid vector from *S. cerevisiae* genomic DNA. The resulting plasmid pKH2 is digested with *Eco*RI and the 1.7 kbp fragment bearing the alpha mating factor gene is purified by preparative agarose gel electrophoresis. Plasmid pRJ148 (a modified pBR322 lacking the *Hind*III site) is digested with *Eco*RI and ligated with the 1.7 kbp fragment to yield the plasmid pRJ159. This DNA is digested with *Hind*III and self-ligated to form plasmid pRJ167, which now has a unique *Hind*III site. Plasmid pRJ167 is digested with *Hind*III and modified by the insertion of a synthetic oligonucleotide adaptor to yield a new plasmid (pRJ178) containing a unique *Hind*III site which is to the 3' side of the promoter and pre-pro-leader and to the 5' side of the translational termination signals in all three reading frames. The *Hind*III site is converted to a *Bam*HI site by digestion with *Hind*III, flush-ending with the Klenow fragment of DNA polymerase I, addition of *Bam*HI linkers and self-ligation to form plasmid pJC193. This plasmid is digested with *Eco*RI, flush-ended with the Klenow fragment of DNA polymerase I, modified by the addition of *Bcl*I linkers, digested with *Bcl*I, and the 1.5 kbp fragment bearing the alpha mating factor gene isolated by preparative gel electrophoresis. This resulting *Bcl*I fragment is treated with calf intestine alkaline phosphatase and then is inserted into the unique *Bam*HI site of pC1/1, destroying the original *Bam*HI site in the process (plasmid pJC194). This DNA is digested with *Bam*HI and self-ligated to remove excess *Bam*HI linkers, resulting in the new alpha mating factor expression plasmid pJC197. The preS-1/preS-2/S ORF in pUC13 described above is digested with *Hin*FI and *Ava*I, and the 0.5 kbp ORF is purified by preparative agarose gel electrophoresis. pUC18 is digested with *Sal*I and *Bam*HI, then ligated to 2 synthetic oligonucleotides. The 5' oligonucleotide consists of a *Sal*I terminus, a *Hind*III site, nucleotides encoding a KEX2 cleavage site, nucleotides encoding amino acids 2 and 3 of preS-1, and a *Hin*FI terminus. The 3' oligonucleotide contains an *Ava*I site, nucleotides encoding the final 8 amino acids of preS-2, the stop codon, a *Hind*III site, and a *Bam*HI terminus. The 0.5 kbp ORF is cloned into this oligonucleotide-linked pUC18 vector. The resulting vector is digested with *Hind*III and blunt-ended with the Klenow fragment of DNA polymerase I. The resulting modified 0.5 kbp preS-1/preS-2 ORF is purified by preparative agarose gel electrophoresis and cloned into pJC197 which had been digested with *Bam*HI and blunt-ended with the Klenow fragment of DNA polymerase I resulting in the preS ORF being operably linked to the pre-pro-leader sequence of alpha mating factor.

The alpha mating factor promoter is active only in cells which are phenotypically α . There are 4 loci in *S. cerevisiae*, known as SIR, which synthesize proteins required for the repression of other normally silent copies of a and α information. Strain JRY188 cells (MAT α , sir3-8, leu2-3, leu2-112, trp1, ura3-52, his4) contain a ts lesion in the SIR3 gene product. As a result, JRY188 cells grown at 35°C are phenotypically a/α and the alpha mating factor promoter is not active; on the other hand, cells grown at 23°C are phenotypically α and thus capable of inducing an expression directed by the alpha mating factor promoter. The recombinant preS-1/preS-2-containing alpha mating factor plasmid is used to transform *S. cerevisiae* strain JRY188 (Brake et al., Proc. Natl. Acad. Sci. USA 81: 4642-4646, 1984) and transformed clones are selected. Cells are grown in synthetic selective (leu⁻) medium at 35°C; subsequently, cells at A⁶⁰⁰ = 0.5 are grown in the same medium at 23°C. Lysates are prepared, resolved by SDS-PAGE, and Western blotted to nitrocellulose. A p21 product is found to be specific to preS-1/preS-2 by virtue of its presence only in transformants and its reactivity with convalescent human HB sera.

The inability of the vector which directs preS-1/preS-2/S expression from the constitutive GAPDH promoter to stably transform *S. cerevisiae* highlights the negative physiological effect of constitutive and high-level pre-S expression upon *S. cerevisiae*; the plasmid pHS56-GAP347/33, which directs S polypeptide expression from this same promoter, efficiently transforms *S. cerevisiae* and such transformed *S. cerevisiae* grow efficiently to production scale. This observation highlights the utility of a shuttle vector which utilizes an inducible, derepressible, or less active constitutive promoter to direct the expression of preS-containing polypeptides in *S. cerevisiae*. In particular, this highlights the utility of the expression vector which utilizes the GAL10 promoter to direct the expression of preS-1/preS-2/S in *S. cerevisiae*. It is obvious to those skilled in the art that the regulatable GAL10 promoter, or GAL1, GAL2, GAL7 or MEL1 promoters which function in an indistinguishable manner, enable the growth of a recombinant *S. cerevisiae* culture to be scaled up to a production-scale volume before synthesis of the recombinant protein is initiated, such that negative effects on the host cell are minimized. Moreover, it is obvious to those skilled in the art that an expression vector containing another regulatable promoter, including but not limited to ADH2 and alpha mating factor, physiologically inducible or derepressible by other means, can be utilized to direct expression of pre-S-containing polypeptides. Furthermore, it is obvious to those skilled in the art that a constitutive promoter less potent than GAPDH, including but not limited to CYC1, drives expression of pre-S-containing polypeptides to a lower percentage of cell protein, such that the negative physiological effects of overexpression would be obviated. It is obvious to those skilled in the art that a suitable assay system, e.g., Western blot or radioimmunoassay, should be utilized in order to assay expression of pre-S-containing polypeptides in this system so that the time of harvesting of the culture for attaining a maximal yield can be optimized.

The genus *Saccharomyces* is composed of a variety of species. Most commonly used is *Saccharomyces cerevisiae*, or baker's yeast, as a host for the recombinant DNA-mediated expression of a variety of foreign polypeptides. However, the distinctions among other species of the genus *Saccharomyces* are not always well-defined. Many of these species are capable of interbreeding with *S. cerevisiae* and are likely to possess regulatable promoters which are analogous or identical to promoters in *S. cerevisiae*, including but not limited to GAL10, ADH2, and/or alpha mating factor promoters. Therefore, it will be obvious to those skilled in the art that, for the expression of pre-S-containing polypeptides, the selection of a host strain extends to other species of the genus *Saccharomyces*, including but not limited to *carlsbergensis*, *uvarum*, *rouxii*, *montanus*, *kluveri*, *elongisporus*, *norbensis*, *oviformis*, and *diastaticus*.

Several yeast genera, such as *Hansenula*, *Candida*, *Torulopsis*, and *Pichia*, have been shown to contain similar metabolic pathways for the utilization of methanol as a sole carbon source for growth. The gene for alcohol oxidase, an enzyme which participates in this metabolic pathway, has been isolated from *Pichia pastoris*. The *P. pastoris* alcohol oxidase promoter has been isolated and shown to be susceptible to methanol induction of expression. Such an inducible promoter is useful for the expression of polypeptides which are negatively selected in yeast. In particular, this promoter has been shown to be active on a plasmid for the inducible expression of the S domain in *P. pastoris* in particulate form. This observation highlights the ability of other yeast genera to function as hosts for the recombinant DNA-mediated expression of S polypeptides in immunologically active form. Therefore, it will be obvious to those skilled in the art that, for the expression of pre-S-containing polypeptides, the selection of a host strain extends to species from other genera of yeast from the Families *Saccharomycetaceae* and *Cryptococcaceae*, including, but not limited to *Pichia*, *Candida*, *Hansenula*, *Torulopsis*, *Kluyveromyces*, and *Saccharomycopsis*.

In recent years, there have been notable successes reported in the expression of recombinant proteins in cells of eukaryotes higher than yeast, in particular in mammalian cell lines and in insect cells transfected with baculovirus expression vectors. Successful expression as an immunogenic particle of both the S domain preS-1 as well as the preS-2 domain linked to the S domain has been achieved. Therefore, it will be

obvious to those skilled in the art that the concept of expressing the complete preS-1/preS-2/S domains in yeast as an immunogenic particle readily extends to expression of these linked domains in cells of higher eukaryotes, including but not limited to mammalian cell lines such as vero, GH3, Ltk⁻ and CHO.

The following examples illustrate the present invention without, however, limiting the same thereto. The disclosure of each reference mentioned in the following examples is hereby incorporated by reference.

EXAMPLE 1

Cloning the preS-1/preS-2/S Gene

Dane particles (subtype ayw) were purified from the plasma of infected individuals by established techniques [Landers *et al.*, J. Virology 23: 368 (1977)]. The HBV genomic DNA resides in a nicked, gapped form in the virion [Hruska *et al.*, J. Virology 21: 666 (1977)]. In order to prepare this DNA for molecular cloning, the endogenous polymerase reaction was employed to produce covalent closed circular double-stranded DNA [Landers *et al.*, J. Virology 23: 368 (1977)]. The DNA was deproteinized by incubation in buffer containing sodium dodecyl sulfate and, Proteinase K followed by extraction with phenol: chloroform:isoamyl alcohol (25:24:1) and concentration by ethanol precipitation. This purified DNA was digested to completion with EcoRI. The E. coli cloning vector pBR322 also was digested with EcoRI, ligated to the digested HBV DNA and used to transform E. coli. Recombinant plasmids were isolated which contain the HBV genome in a circularly permuted orientation about the unique EcoRI site (pHBV/AYW-1, Figure 1A), which divides the complete preS-1/preS-2/S coding region into a 5' domain of 0.4 kbp and a 3' domain of 0.8 kbp [Galibert *et al.*, Nature 281: 646 (1979)]. These two domains were subcloned for the eventual reassembly of the entire gene. pUC19 was digested with EcoRI and BamHI, then ligated to a synthetic oligonucleotide which consists of the final 5 nucleotides of the coding region, the stop codon, a HindIII site, and a BamHI end. The structure of this oligonucleotide is

ATACATTTAAAGCTTG
TGTAATTTTGAACCTAG

The 3' portion of the preS-1/preS-2/S gene, consisting of a 0.8 kbp EcoRI-AccI fragment was cloned into this vector (pUC19/DSD, Figures 1A and 1B).

The 5' portion was subcloned into pUC18 in either of two ways, depending upon whether the complete ORF was to be expressed or the putative hydrophobic signal sequence (amino acids 2-15) was to be eliminated. For the first strategy, pUC18 was digested with HindIII and EcoRI and ligated to 72 bp synthetic oligonucleotide which reconstitutes the complete ORF from the BamHI site upstream to the distal ATG through a 10 bp nontranslated leader sequence to a HindIII compatible terminus. The structure of this oligonucleotide is:

AGCTTACAAAACAAAATGGGGCAGAATCTTTCCACCAGCAATCCTCTGGGATTTTT
ATGTTTTGTTTTACCCCGTCTTAGAAAGGTGGTCGTTAGGAGACCCTAAAAA

TCCCGACCAACAGTTG
AGGGCTGGTGGTCAACCTAG

(the natural sequence contains C rather than T; The above change destroys the HinfI site without changing the encoded amino acid.) For the second strategy, there was ligated a 30 bp oligonucleotide which performed an identical function as the 72 bp oligonucleotide but which eliminated the coding region for amino acids 2-15. The structure of this oligonucleotide is

AGCTTACAAAACAAAATGGACCACCAAGTTG
ATGTTTTGTTTTACCTGGTGGTCAACCTAG

The 0.4 kbp BamHI-EcoRI fragment of the 5' domain then was ligated into either of these oligonucleotide-linked cloning vectors (pUC18/USDA, pUC18/USDC, Figures 1A and 1B). The 5' pUC18 and 3' pUC19 clones were amplified by growth in *E. coli*, and the coding regions were digested from the isolated plasmids as HindIII-EcoRI fragments. These fragments were ligated, digested with HindIII, and the complete ORF with HindIII termini was cloned into pUC13 which had been digested with HindIII (pUC13/PSSA, pUC13/PSSC: Figures 1B and 1C). The complete ORF from this vector was purified by preparative agarose gel electrophoresis for cloning into the GAPDH or GAL10 promoter (YE52) or ADH-2 promoter expression systems, as described in Examples 2, 3 and 4.

10 EXAMPLE 2

15 Use of the GAPDH promoter to direct expression of preS-1/preS-2/S in *S. cerevisiae*

The PBR322 plasmid containing the GAPDH expression cassette [Holland and Holland, J. Biol. Chem. 255: 2596 (1980)] has a unique HindIII cloning site into which the 1.1 kbp preS-1/preS-2/S ORF with HindIII termini (described in Example 1) was cloned (pEGAP/PSSA, pEGAP/PSSC, Figure 1C). The expression cassettes (containing the HBV genes) were removed from the PBR322 plasmid by SphI digestion and preparative agarose gel electrophoresis. The expression cassettes then were cloned into the shuttle vector pC1/1 [Beggs, Nature 275: 104 (1978); Rosenberg et al., Nature 312: 77 (1984)] which had been digested previously with SphI (pYGAP/PSSA, pYGAP/PSSC, Figure 1C). The pC1/1 plasmid containing the expression cassettes was used to transform *S. cerevisiae* strain 2150-2-3; however, few stable recombinant yeast clones could be recovered from selective plates following plating out of the transformation mixture. The suspected toxicity of the pre-S containing product for *S. cerevisiae* was confirmed by removal of the pre-S1/preS-2/S coding region and creation of a frameshift mutation by BamHI digestion and religation of the plasmid; DNA prepared in this manner efficiently transformed yeast.

30 EXAMPLE 3

35 Use of the GAL10 promoter to direct expression of preS-1/preS-2/S in *S. cerevisiae*

The YE52 *E. coli*/*S. cerevisiae* shuttle vector drives expression of foreign genes inserted at a unique HindIII site from the galactose-inducible GAL10 promoter [Broach et al., In Experimental Manipulation of Gene Expression, p83, Academic Press (1983)]. In addition, this vector contains partial 2E circle sequences (ori and one inverted repeat) for propagation in *S. cerevisiae*, LEU2 for selection in *S. cerevisiae*, and the ori and bla sequences for amplification and selection, respectively, in *E. coli*. The 1.1 kbp preS-1/preS-2/S ORF with HindIII termini (described in Example 1) was cloned into the unique HindIII site (pYGAL/PSSA, pYGAL/PSSC, Figure 1C), and the resultant plasmid was used to transform *S. cerevisiae* strain BY-19 obtained from the laboratory of Dr. J. R. Broach at Princeton University. Recombinant clones were isolated and examined for expression of the preS-1/preS-2/S polypeptide. Clones were grown in synthetic selective (leu⁻) glycerol-lactic acid medium [0.67% (w/v) yeast nitrogen base without amino acids, 0.004% adenine, 0.004% uracil, 1% succinate, 0.005% tyrosine, 0.002% arginine, 0.006% isoleucine, 0.004% lysine, 0.001% methionine, 0.006% phenylalanine, 0.006% threonine, 0.004% tryptophan, 0.001% histidine, 0.6% sodium hydroxide, 2% (v/v) lactic acid, 3% (v/v) glycerol]. Production of the gene product was induced by the addition of galactose to 2% (w/v) after the yeast had grown to an A₆₀₀ = 0.3. Expression of the desired antigen was verified by the detection of HBsAg by Ausria^R (Abbott) reactivity, polymerized human albumin binding activity [Machida et al., Gastroenterology 86: 910 (1984)] and the presence of p39 in Western blots which were developed using convalescent human serum and radiolabelled Staphylococcus aureus protein A. These recombinant clones served as seed cultures for the large-scale fermentation and isolation described in Example 6.

Exempl 4

5 Use of the ADH2 promoter to direct expression
 of preS-1/preS-2/S in *S. cerevisiae*

10 The pADH2Δ67(-1) *E. coli* cloning vector contains sequences which are capable in *S. cerevisiae* of driving expression of foreign genes inserted at a unique HindIII site from the ADH2 derepressible promoter [Russell et al., J. Biol. Chem. 258: 2674 (1983); E. T. Young, submitted for publication]. The unique HindIII site is positioned between nucleotide -1 of the 5' nontranslated flanking sequences and the transcriptional terminator of the ADH2 gene. pADH2Δ67(-1) was digested with BamHI and EcoRI, made flush-ended with
 15 the Klenow fragment of DNA polymerase I, and the 4.9 kbp fragment containing the ADH2 promoter and terminator was purified by preparative agarose gel electrophoresis. pUC7 was digested with PstI, made flush-ended with T4 DNA polymerase, and ligated to the 4.9 kbp ADH2 fragment. The resulting plasmid was digested with Sall, and the 4.9 kbp fragment was purified by preparative agarose gel electrophoresis. pUC18 was digested with HindIII, made flush-ended with the Klenow fragment of DNA polymerase I, and
 20 self-ligated. The resulting plasmid was digested with Sall and ligated to the 4.9 kbp Sall fragment, creating the vector pUC18ΔHindIII-ADH2 (Figure 1). The two different 1.1 kbp preS-1/preS-2/S ORFs with HindIII termini (described in Example 1) were ligated into the HindIII site of this vector. The resulting plasmid (pEADH2/PSSΔ, pEADH2/PSSC, Figure 1C) was digested with Sall, and the 6.1 kbp fragment was ligated into the Sall site of pC1/1 creating the plasmids pYADH2/PSSΔ, pYADH2/PSSC (Figure 1C). These
 25 recombinant plasmids were used to transform *S. cerevisiae* strain 2150-2-3 obtained from the laboratory of Dr. L. Hartwell at the University of Washington. Recombinant clones were isolated and examined for expression of the preS-1/preS-2/S polypeptide. Clones were grown in synthetic selective (leu⁻) medium containing 0.3% (w/v) glucose. Cells were grown for 48 hours at 30 °C to an A⁶⁰⁰ = 1.5, during which time glucose depletion had derepressed the ADH2 promoter. Alternatively the clones were grown in synthetic
 30 selective (leu⁻) medium containing 2% glucose as a carbon source. Cells were grown for 24 hours at 30 °C to an A⁶⁰⁰ of either 0.1 or 1.0, at which time larger flasks or fermenters containing complex medium with 1.6% glycose as a carbon source were inoculated (inoculum size = 10% vol/vol). Cells were grown for an additional 45 hours as described above to an A⁶⁰⁰ = 12.0-14.0, during which time glucose depletion had derepressed the ADH2 promoter. Expression of the desired antigen was verified by the detection of HBsAg
 35 by AUSRIA^R (Abbott) reactivity, polymerized human albumin binding activity, and the presence of p39 in Western blots which were developed using convalescent human serum and radiolabelled *Staphylococcus aureus* protein A. A selected recombinant clone served as a seed culture for the scale-up fermentation and isolation described in Example 7.

40 Example 5

Use of the alpha mating factor promoter
 and pre-pro-leader to direct expression of
 45 preS-1/preS-2 in *S. cerevisiae*

50 The alpha mating factor gene MF_α1 had been cloned onto a plasmid vector from *S. cerevisiae* genomic DNA [Kurjan et al., Cell 30: 933 (1982); Singh et al., Nucleic Acids Res. 11: 4049 (1983)]. The resulting plasmid pKH2 was digested with EcoRI and the 1.7 kbp fragment bearing the alpha mating factor gene was purified by preparative agarose gel electrophoresis. Plasmid pRJ148 (a modified pBR322 lacking the HindIII site) was digested with EcoRI and ligated with the 1.7 kbp fragment to yield the plasmid pRJ159. This DNA was digested with HindIII and self-ligated to form plasmid pRJ167, which now has a unique HindIII site.
 55 Plasmid pRJ167 was digested with HindIII and modified by the insertion of a synthetic oligonucleotide adaptor to yield a new plasmid (pRJ178) containing a unique HindIII site which is to the 3' side of the promoter and pre-pro-leader and to the 5' side of the translational termination signals in all three reading frames (Figure 2). The HindIII site was converted to a BamHI site by digestion with HindIII, flush-ending with

the Klenow fragment of DNA polymerase I, addition of BamHI linkers and self-ligation to form plasmid pJC193. This plasmid was digested with EcoRI, flush-ended with the Klenow fragment of DNA polymerase I, modified by the addition of BclI linkers, digested with BclI, and the 1.5 kbp fragment bearing the alpha mating factor gene isolated by preparative gel electrophoresis. This resulting BclI fragment was treated with calf intestine alkaline phosphatase and was inserted into the unique BamHI site of pC1/1, destroying the original BamHI site in the process (plasmid pJC194). This DNA was digested with BamHI and self-ligated to remove excess BamHI linkers, resulting in the new alpha mating factor expression plasmid pJC197 (Figure 3). The pUC13/PSSC plasmid (described in Example 1) was digested with HinFI and AvaI, and the 0.45 kbp ORF was purified by preparative agarose gel electrophoresis (Figure 4A). pUC18 was digested with SalI and BamHI, then ligated to 2 synthetic oligonucleotides. The 5' oligonucleotide consists of a SalI terminus, a HindIII site, nucleotides encoding a KEX2 cleavage site, nucleotides encoding amino acids 2 and 3 of preS-1, and a HinFI end. The structure of this oligonucleotide is

TCGACAAGCTTGGATAAGAGAGGGCAG
GTTCGAACCTATTCTCTCCCGTCTTA

The 3' oligonucleotide contains an AvaI site, nucleotides encoding the final 8 amino acids of preS-2, the stop codon, a HindIII site, and a BamHI end. The structure of this oligonucleotide is

TCGAGGATTGGGGACCCTGCGCTGAACTAAAGCTTG
CCTAACCCCTGGGACGCGACTTGATTTCGAACCTAG

The 0.4 kbp ORF was cloned into this oligonucleotide-linkered pUC18 vector (Figures 4A and 4B). The resulting vector (pUC18/PSΔS) was digested with HindIII and blunt-ended with the Klenow fragment of DNA polymerase I resulting in an expression cassette containing the preS1/preS2 ORF operably linked to the alpha factor prepro-leader. This cassette was purified by preparative agarose gel electrophoresis and cloned into pJC197 which had been digested with BamHI and blunt-ended with the Klenow fragment of DNA polymerase I (pYαMF/PSΔS, Figure 4B), resulting in the preS1/preS2 ORF operably linked to the alpha factor pre-pro-leader.

The alpha mating factor promoter is active only in cells which are phenotypically α [Brake et al., Mol. Cell Biol. 3: 1440 (1983)]. There are 4 loci in *S. cerevisiae*, known as SIR, which synthesize proteins required for the repression of other normally silent copies of α and α information [Rine et al., Genetics 93: 877 (1979)]. Strain JRY188 cells (MAT α , sir3-8, leu2-3, leu2-112, trp1, ura3-52, his4) contain a temperature-sensitive lesion in the SIR3 gene product. As a result, JRY188 cells grown at 35°C are phenotypically α/α and the alpha mating factor promoter is not active; on the other hand, cells grown at 23°C are phenotypically α and thus capable of inducing an expression directed by the alpha mating factor promoter [Brake et al., Proc. Natl. Acad. Sci. USA 81: 4642 (1984)]. The recombinant preS-1/preS-2-containing alpha mating factor plasmid was used to transform *S. cerevisiae* strain JRY188 obtained from the laboratory of Dr. Jasper Rine at the University of California at Berkeley and transformed clones were selected. Cells were grown in synthetic selective (leu⁻) medium at 37°C; subsequently, cells at $A^{600} = 0.5$ were grown in the same medium at 23°C. Lysates were prepared, resolved by SDS-PAGE, and Western blotted to nitrocellulose. A p21 product was found to be specific to preS-1/preS-2 by virtue of its presence only in transformants and its reactivity with convalescent human HB sera.

EXAMPLE 6

Purification of preS-1/preS-2/S in particulate form by means of immune affinity chromatography

Recombinant *S. cerevisiae*, constructed as described in Example 3 (complete preS sequence including amino acids 2-15), were grown in a 16 liter New Brunswick Scientific fermenter charged with 9.0 liters of synthetic selective glycerol-lactic acid medium, composed as described in Example 3. Fermentation conditions were 250 rpm agitation, 2.5 liters air/minute at 30°C. After growth to $A^{600} = 0.25$, product synthesis was induced by the addition of galactose [2% (w/v)] and fermentation was continued for an additional 33 hours to a final $A^{600} = 2.40$. The yeast cells were harvested by microfiltration in an Amicon DC-10 unit, suspended in 30 ml buffer A [0.1M Na₂HP0₄, pH 7.2, 0.5M NaCl], and broken in a Stansted pressure cell for seven passages at 75-85 pounds per square inch. The broken cell suspension (31 gm wet

cell weight) was diluted with 120 ml buffer A, Triton X-100® was added to a final concentration of 0.5% (w/v), and the suspension was clarified by centrifugation at 10,000 X g for 20 min. at 4°C. The clarified broth was decanted and incubated with Sepharose 4B coupled with antibodies to HBsAg [McAleer et al., Nature 307: 178 (1984)] for 19 hours at 4°C to adsorb the antigen onto the resin. After the incubation period, the slurry was warmed to room temperature for all subsequent steps and degassed under vacuum for 15 min. The degassed slurry was poured into a 2.5 x 40 cm column. When the column had been packed fully, unbound protein was washed away with buffer A. The antigen was eluted with 3M KSCN in buffer A. Fractions containing antigen were dialyzed against 0.007M Na₂HPO₄, pH 7.2, 0.15M NaCl at 4°C and pooled to form the Dialyzed Affinity Pool containing 1.08 mg of protein in 20 ml. Sixteen ml of Dialyzed Affinity Pool was diluted to 40 mcg/ml with 5.6 ml 0.006M Na₂HPO₄, pH 7.2, 0.15M NaCl. The product was sterilized by filtration through a Millex-GV 0.22 µm membrane. The identity of the product in the Dialyzed Affinity Pool was verified by the detection of HBsAg by Ausria® reactivity and polymerized human albumin binding activity.

15 EXAMPLE 7

Purification of preS-1/preS-2/S in Particulate Form by Means of Immune Affinity Chromatography

Recombinant *S. cerevisiae*, constructed as described in Example 4 (complete preS sequence including amino acids 2-15), were grown in a 16 liter New Brunswick Scientific fermenter charged with 9.0 liters of complex medium, made as described (YPD in Methods in Yeast Genetics p. 61, Cold Spring Harbor Laboratory, Cold Spring Harbor, NY), except that HySoy (amber) was substituted for peptone. Fermentation conditions were 500 rpm agitation, 5.0 liters air/minute at 30°C for 44 hours from A⁶⁰⁰ = 0.65 to A⁶⁰⁰ = 9.50. The yeast cells were harvested and lysed, and the preS-1/preS-2/S product purified as described in Example 6. The identity of the product was verified by the detection of HBsAg by Ausria® reactivity, polymerized human albumin binding activity, and the presence of p39 in Western blots which were developed using convalescent human serum and radiolabelled *Staphylococcus aureus* Protein A.

Claims

1. A vaccine against hepatitis B disease comprising a polypeptide and a physiologically acceptable diluent, characterised in that said polypeptide has the pre-S1 domain lacking amino acids 2-15, the pre-S2 domain and the S domain.

35 Patentansprüche

1. Impfstoff gegen die Krankheit Hepatitis B, enthaltend ein Polypeptid und ein physiologisch verträgliches Verdünnungsmittel, dadurch gekennzeichnet, daß das genannte Polypeptid die prä-S1-Domäne, der die Aminosäuren 2-15 fehlen, die prä-S2-Domäne und die S-Domäne aufweist.

40 Revendications

1. Vaccin contre la maladie de l'hépatite B, comprenant un polypeptide et un diluant physiologiquement acceptable, caractérisé en ce que ledit polypeptide possède le domaine pré-S1 sans les acides aminés 2-15, le domaine pré-S2 et le domaine S.

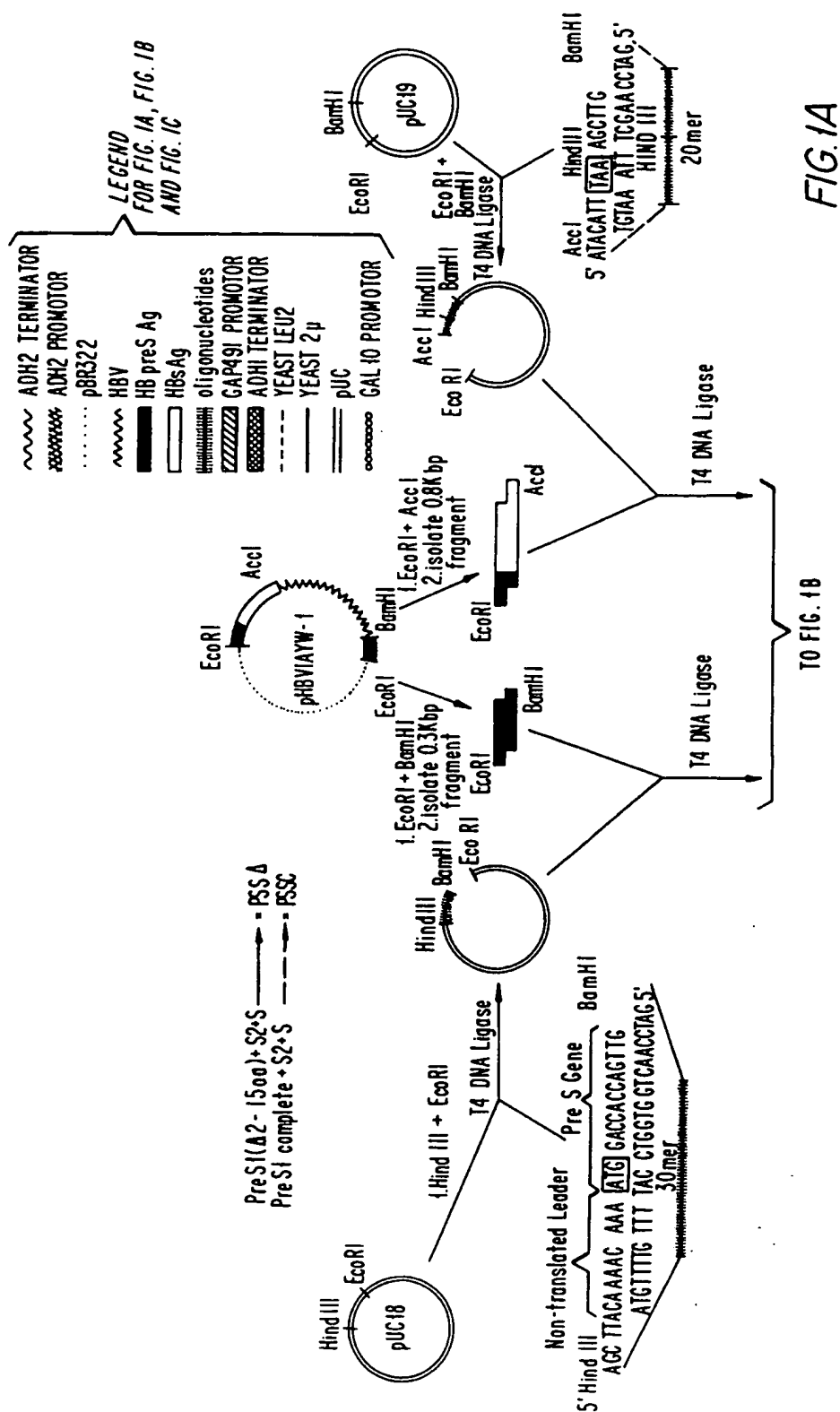
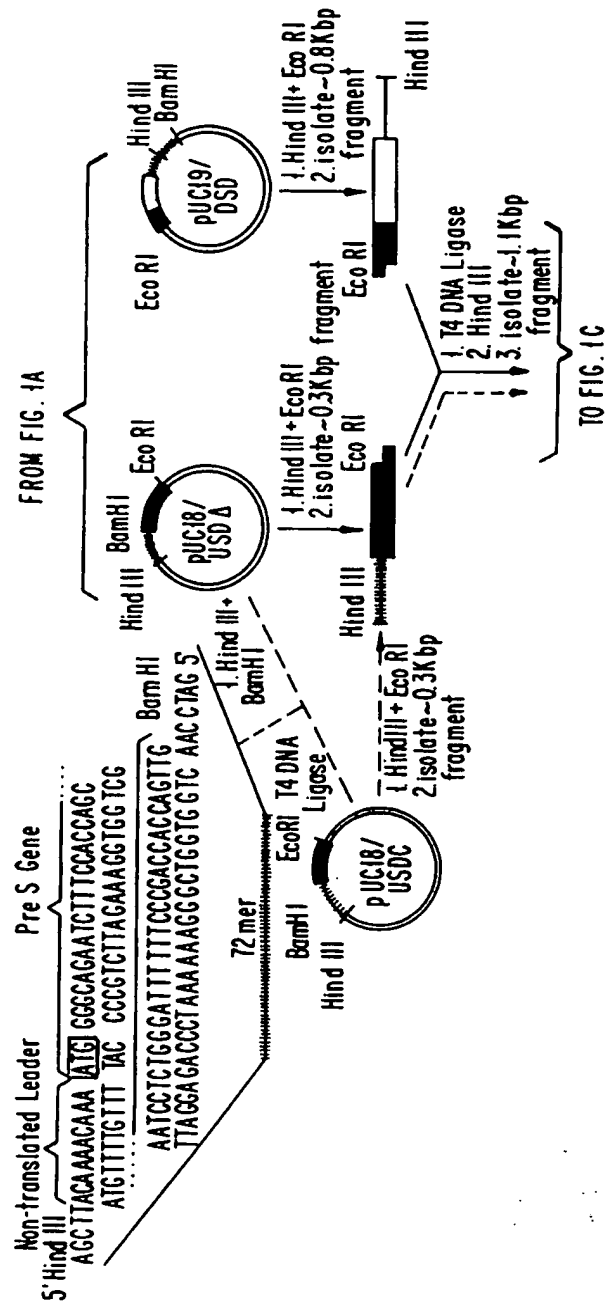


FIG. 1B



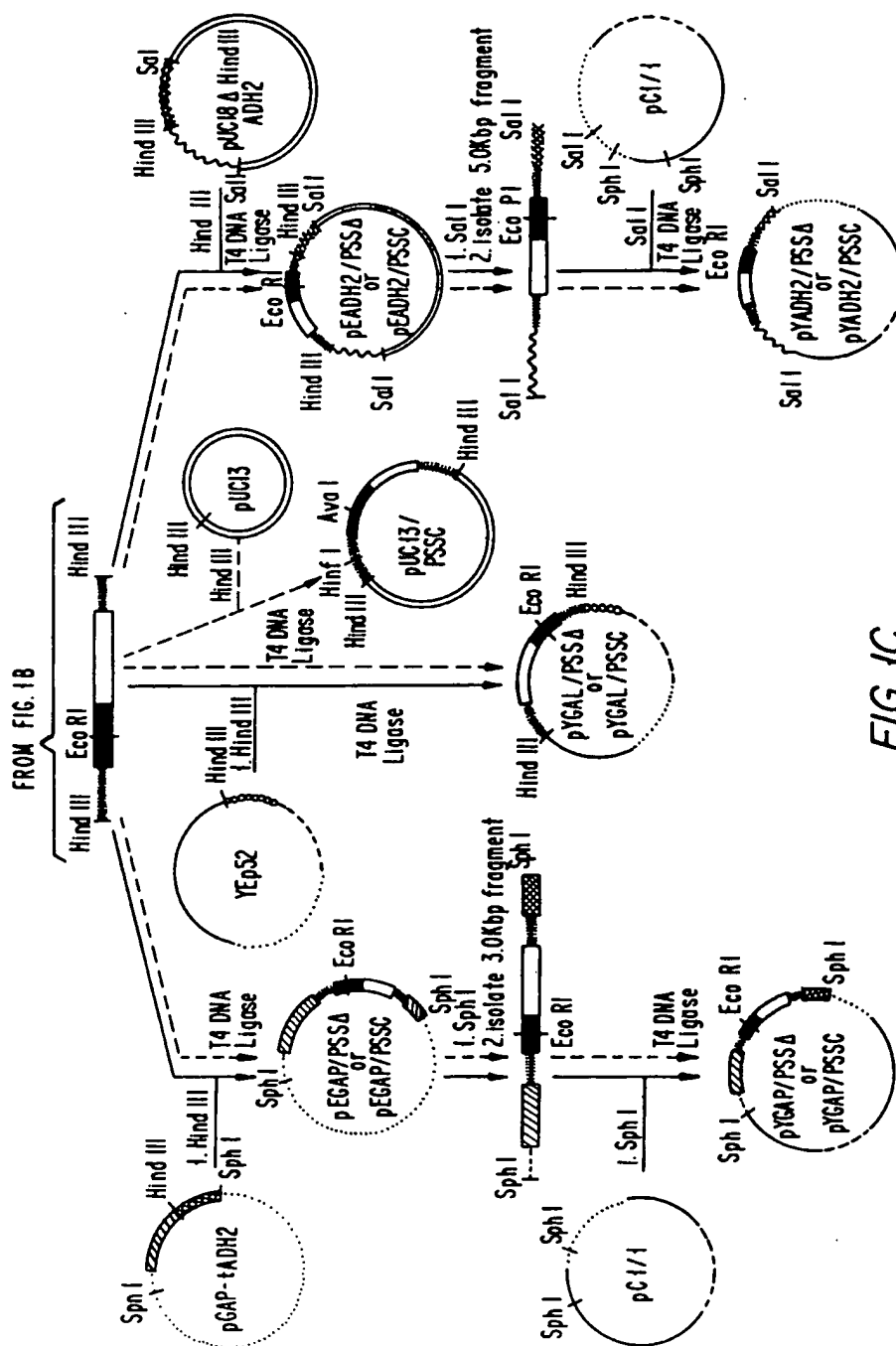


FIG. 1C

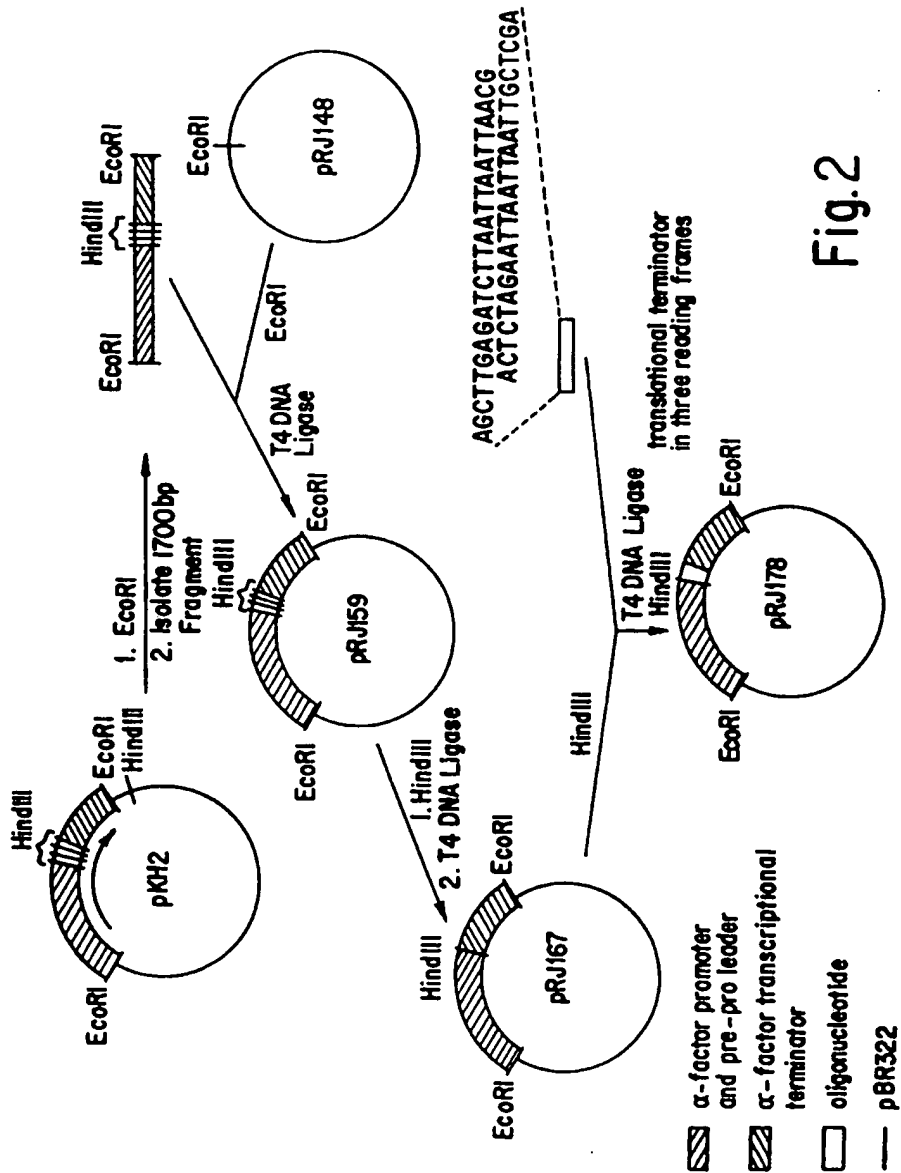
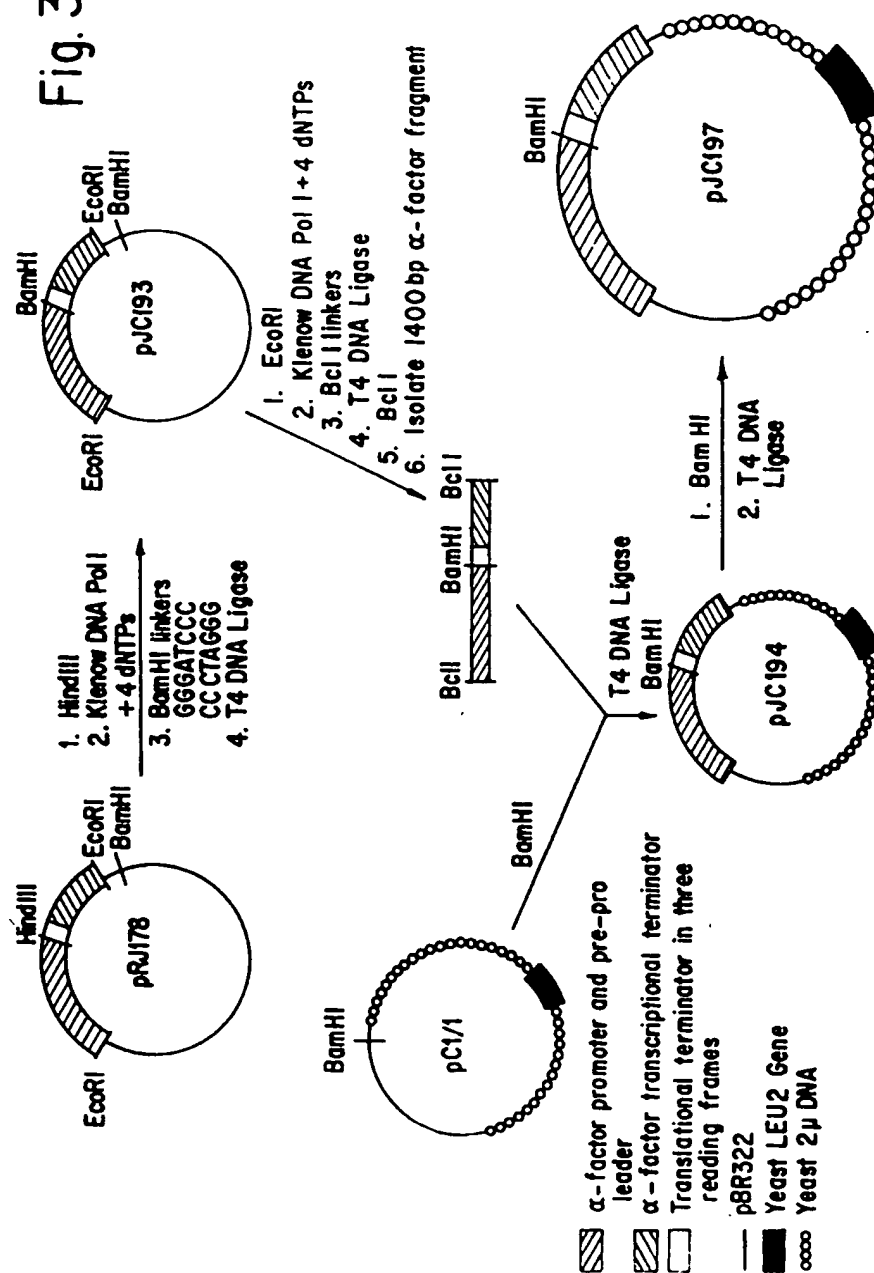


Fig. 3



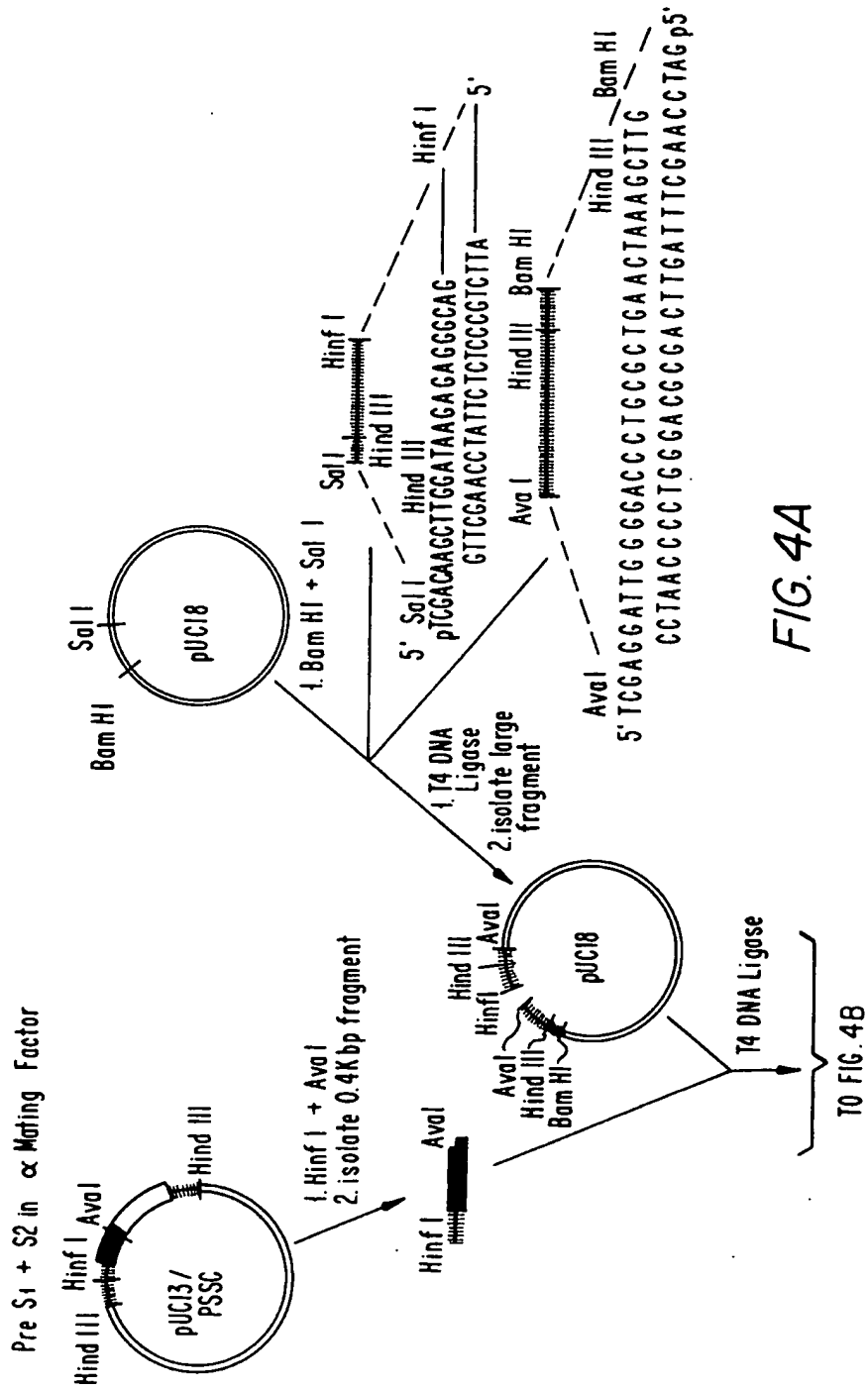


FIG. 4A

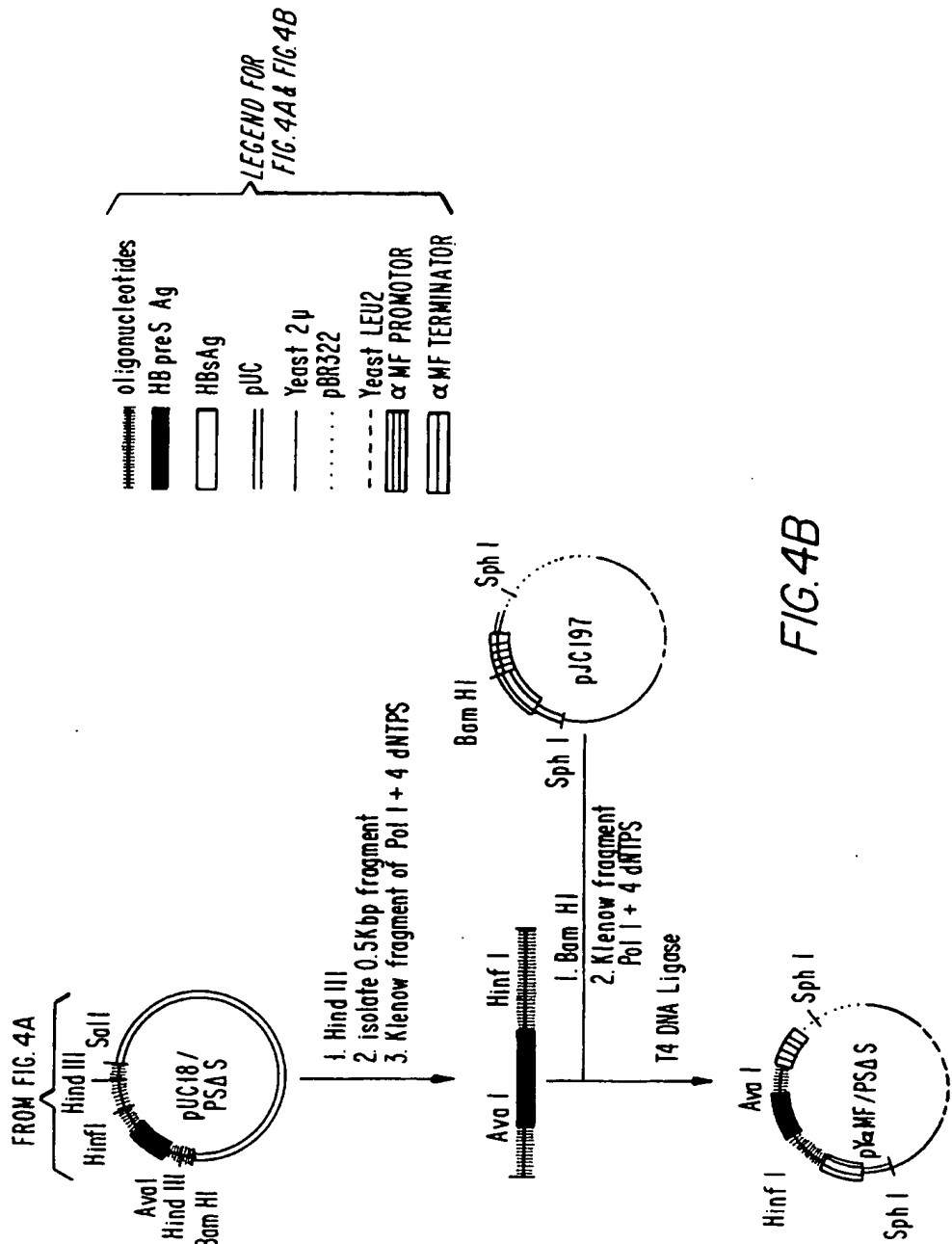


FIG. 4B